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GEOLOGY OF THE ONO QUADRANGLE, SHASTA AND TEHAMA COUNTIES, CALIFORNIA

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BULLETIN 192
California Division of Mines and Geology
Ferry Building, San Francisco, 1969

GEOLOGY OF THE ONO QUADRANGLE, SHASTA AND TEHAMA COUNTIES, CALIFORNIA

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CONTENTS

	Page
ABSTRACT	5
INTRODUCTION	7
PRE-CRETACEOUS ROCKS	7
Abrams Mica Schist and Salmon Hornblende Schist	7
Copley Greenstone	9
Bragdon (?) Formation	9
Shasta Bally Batholith	10
Serpentinite	10
CRETACEOUS ROCKS	11
Budden Canyon Formotion	11
Rector Member	11
Ogo Member	11
Roaring River Member	18
Chickabally Member	19
Huling Member	19
Bald Hills Member	21
Gas Point Member	22
Sandstone Dikes	23
Structural Geology	24
North-Trending Faults	24
Northeast-Trending Faults	24
Northwest-Trending Faults	24
Folds	25
Unconformities	25
Other Discordant Relationships	25
CENOZOIC ROCKS	26
Tehama Formation	26
Red Bluff Formation	26
Terraces and Terrace Deposits	28
REFERENCES	28

Illustrations

		Page
Plate 1.	Geologic map and sections of the Ono quadrangle	In pocket
Figure 1.	Index map	8
2.	Summary of lithostratigraphic and biostratigraphic classifications used in the Ono quadrangle	12
3.	Fault pattern, lithologic units, and current lineations in the Ono and Chanchelulla Peak quadrangles	16
Photo 1.	Parting lineation, the commonest current structure encountered in the Budden Canyon Formation, is especially well developed in the Ogo Member	13
2.	Substratal lineations show slight angular deviation from parting lineation of the same bed. Upper Ogo Member, Wells Creek, Tehama County	13
3.	Intrastratal folding, Ogo Member, Wells Creek, Tehama County	14
4.	Minor angular discordance between sandstone bed and underlying siltstone beds. Wells Creek, Ogo Member, Budden Canyon Formation, Tehama County	15
5.	Divergence of beds around twisted, isolated, and unoriented sandstone blocks in a mudstone matrix, Ogo Member, Wells Creek, Tehama County	17
6.	Transverse fault, north bank of Middle Fork of Cottonwood Creek, separates Ogo Member (right) from Roaring River Member (left)	18
7.	Flute casts on prominent sandstone bed in the Chickabally Member, Dry Creek, Tehama County	20
8.	Two *Pseudouhligella* in a clast in the lower conglomerate of the Bald Hills Member, North Fork of Cottonwood Creek	21
9.	Conglomerate bed in the Bald Hills Member, Middle Fork of Cottonwood Creek	22
10.	Typical clasts from the Red Bluff Formation	27

ABSTRACT

The Ono quadrangle is on the west side ot the Sacramento Valley in the foothills of the northern California Coast Ranges. Marine Cretaceous rocks are exposed at the surface or underlie younger rocks throughout most of the quadrangle. In the northern part, non-marine deposits of Cenozoic age lap directly onto pre-Cretaceous metamorphic and igneous rocks of the southeastern Klamath Mountains. Metamorphic rocks crop out mainly in the northwest corner of the quadrangle and include the Abrams Mica Schist and Salmon Hornblende Schist of probable pre-Devonian age, the Copley Greenstone of possible Devonian age, and the Bragdon (?) Formation of Devonian or Mississippian age. These units have been intruded by ultrabasic rocks, now serpentinized, and by the Shasta Bally batholith of Late Jurassic age.

Cretaceous rocks, ranging in age from Hauterivian to Turonian, unconformably overlie the metamorphic and igneous rocks and comprise a single unit, the Budden Canyon Formation, which is 7,000 to 22,000 feet thick. Basal beds of the Budden Canyon Formation are progressively younger toward the north and east, and the section also thins in this direction. The Budden Canyon Formation is composed predominantly of mudstone, siltstone, and fine-grained sandstone. Conglomerate, pebbly mudstone, and medium- to coarse-grained sandstone predominate in restricted parts of the section; limestone concretions and beds are common minor constituents. Concentrations of coarse clastic rocks form outcrop belts that divide the formation into seven members. Rocks of the Budden Canyon Formation generally dip homoclinally east and southeast from the Klamath Mountains and are relatively undeformed except in zones of post-Cretaceous faulting where the rocks are strongly sheared and contorted. Sedimentary structures, including parting lineation, ripple marks, substratal lineations, slump structures, and intrastratal deformation, are common in sandstones, but are virtually absent in finer-grained rocks. Flow lineations, ripple marks, and cross stratification indicate a major current direction toward the south or southeast during deposition of these sediments.

Non-marine fluvial and pyroclastic rocks of Cenozoic age are included in two formations. The Tehama Formation, including the prominent Nomlaki Tuff, is of Pliocene age, and is composed mostly of sands and gravels which unconformably overlie older rocks. The Red Bluff Formation of Pleistocene age is composed of cobble and boulder gravels which unconformably overlap all other rock units in the quadrangle. These deposits were removed from the western part of the quadrangle following post-Pleistocene uplift of the Klamath Mountains and northern Coast Ranges. As many as six post-Red Bluff terrace levels have been distinguished along the major streams. Most terraces have a veneer of gravel similar to gravel of the Red Bluff Formation.

GEOLOGY OF THE ONO QUADRANGLE, SHASTA AND TEHAMA COUNTIES, CALIFORNIA

BY M. A. MURPHY, P. U. RODDA, AND D. M. MORTON

INTRODUCTION

The rocks in the Ono quadrangle are discussed under three headings: (1) the pre-Cretaceous igneous and metamorphic rocks; (2) the marine Cretaceous rocks; (3) the late Cenozoic fluvial deposits and volcanics.

The Cretaceous rocks are part of the thick generally homoclinal sequence of Mesozoic rocks that crop out along the western margin of the Sacramento Valley. They are exposed or underlie Cenozoic rocks throughout the quadrangle except in the northern part, where they lap onto igneous and metamorphic rocks of the southeastern Klamath Mountains.

Late Cenozoic non-marine fluvial and pyroclastic deposits, now exposed in the eastern part of the quadrangle, formerly covered most of the pre-Cenozoic rocks of the quadrangle but have been removed from most of the western part of the quadrangle since the Pleistocene.

Gold, lead, zinc, and manganese properties have been worked in the Ono quadrangle and are described in Averill (1933, p. 9, 50; 1938, p. 115, 120, 122; 1939, p. 169, 180, 189, 190); Trask *et al.* (p. 266–267).

This project has been financed largely by National Science Foundation Grant 5031. The division of responsibility for the mapping was as follows: Morton mapped and described the igneous and metamorphic rocks; Rodda had primary responsibility for the Upper Cretaceous and shared with Murphy the mapping of the Cenozoic rocks; Murphy had responsibility for the Lower Cretaceous rocks and part of the Cenozoic rocks, and compilation of the report. Mapping was done at various times from 1951 to 1963.

PRE-CRETACEOUS ROCKS

Pre-Cretaceous rocks ranging in age from probably pre-Devonian to Late Jurassic crop out in the northern part of the Ono quadrangle. The oldest rocks are referred to the Abrams Mica Schist and Salmon Hornblende Schist of probable pre-Devonian age. Rocks of probable Paleozoic age include the Copley Greenstone and the Bragdon (?) Formation. These rocks were intruded by granitic rocks of the Shasta Bally batholith of probable Late Jurassic age, and by ultrabasic rocks, now serpentinized, of possible post-batholith age.

Abrams Mica Schist and Salmon Hornblende Schist

Schistose rocks that crop out west of the Shasta Bally batholith in the northwest part of the Ono quadrangle are predominantly impure quartzite, muscovite-quartz, muscovite-biotite, biotite, chlorite-epidote, and hornblende schists. Marble and talc-actinolite rocks are minor constituents.

These rocks were assigned by Hinds (pl. 3) to two formations originally described by Hershey, the Abrams Mica Schist below and the Salmon Hornblende Schist above. The type localities of these units are in the Trinity Alps about 50 miles north of the Ono quadrangle. Davis and Lipman, in a note on the type area of these formations, stated that rocks previously mapped as Abrams Mica Schist comprise two distinct units, the Grouse Ridge Formation above and the Stuart Fork Formation below, separated by the Salmon Formation. The name Abrams was suppressed. The Grouse Ridge Formation is composed of feldspathic and micaceous quartz schists, almandine-hornblende rocks, hornblende schists and gneisses, quartz and silicate-bearing marbles, and calc-schists. Davis and Lipman tentatively assigned to the Grouse Ridge Formation similar rocks which crop out south of Weaverville, and which extend 25 miles southeastward into the Ono quadrangle. In the Weaverville quadrangle, Irwin (1960a, 1963) retained Hershey's nomenclature but indicated that the Abrams Mica Schist is probably younger than the Salmon Hornblende Schist and noted that the Abrams Mica Schist may be equivalent to the Grouse Ridge Formation of Davis and Lipman. In the French Gulch quadrangle, north of the Ono quadrangle, Albers (p. 9 and pl. 1) mapped these metamorphic rocks as a single unit, as did the present authors.

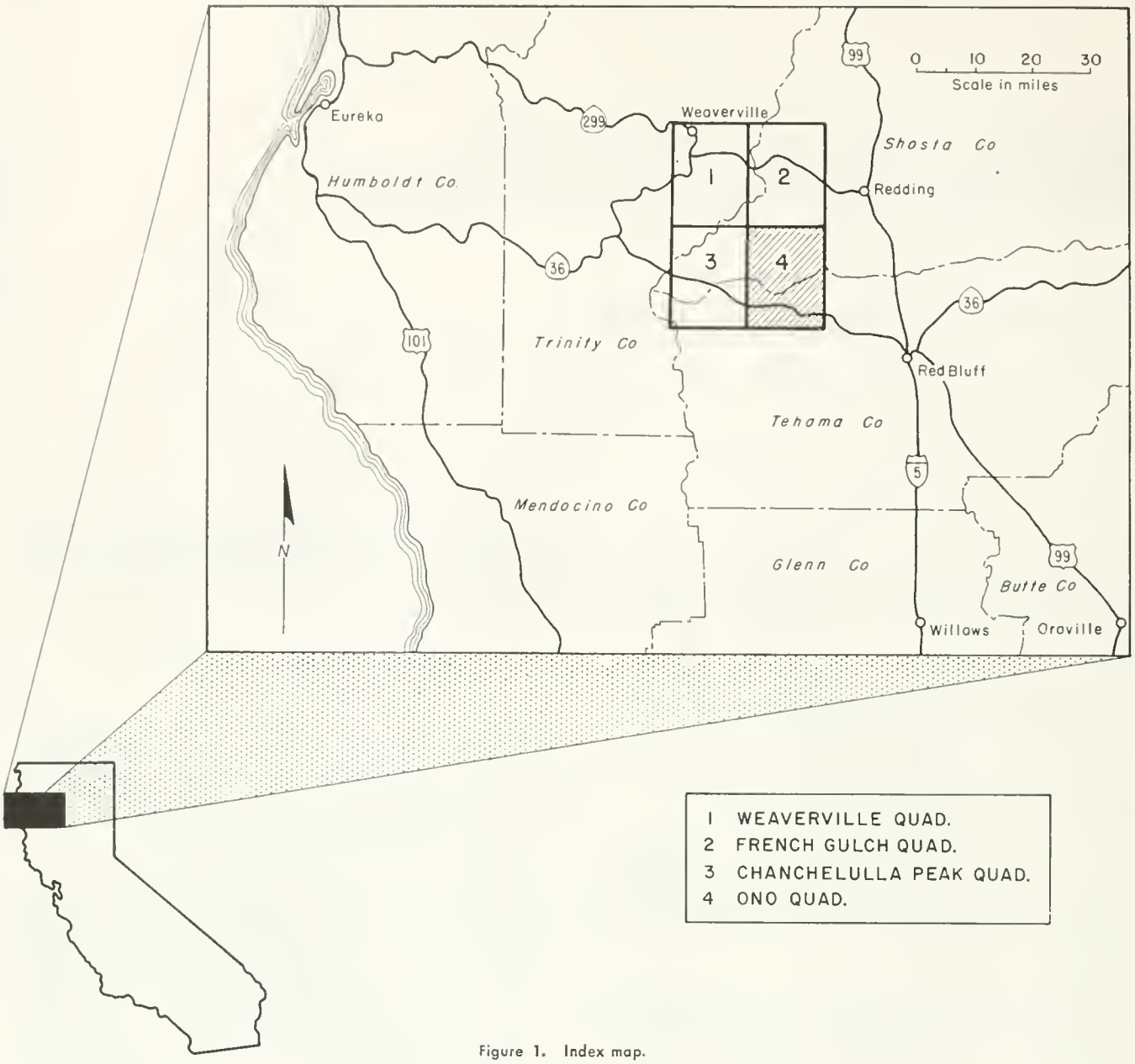

Figure 1. Index map.

The quartz mica schists and quartzite range in texture from fine foliate to massive granoblastic. Muscovite-bearing schist appears to be more widespread than biotite schist. Potash feldspar is commonly present in small amounts; magnetite is a very common accessory. Garnet-biotite schist is a sparse constituent in the southwestern exposures of this unit in the Ono quadrangle.

Chlorite and chlorite-epidote schists generally are dark green with massive to finely foliate lepidoblastic texture. Chlorite, epidote, albite and quartz commonly compose up to several percent of these rocks. Biotite, muscovite, hornblende, tremolite-actinolite, garnet, potash feldspar, and calcite are also present. Accessories include zircon, apatite, magnetite and secondary hematite. Nearly pure chlorite schist is common along the North Fork of Cottonwood Creek, where some exposures contain veins and blebs of massive white quartz that have been prospected for gold. Spotted greenschist containing albite porphyroblasts is locally common and well-exposed on Wilson Creek.

Dark colored nematoblastic hornblende and actinolite schists occur mainly near the quadrangle boundary along Jerusalem Creek. Hornblende or actinolite, plagioclase (oligoclase) and epidote are the major constituents. Chlorite, potash feldspar, biotite, quartz, and calcite are present in smaller percentages, and zircon, magnetite and apatite are accessories. A few discontinuous masses of talc-actinolite rock are exposed near the quadrangle's north boundary on the North Fork of Cottonwood Creek.

Lens-shaped masses of fine- to coarse-grained, gray to light brown impure schistose marble are sparsely scattered throughout these metamorphic rocks. In ad-

dition to anhedral calcite, the marble contains small amounts of chlorite, biotite, muscovite, epidote, and quartz.

Mineral assemblages indicate that most of these rocks belong to the greenschist facies of regional metamorphism. Assemblages containing biotite, almandine, and epidote suggest local formation of the quartz-albite-epidote-almandine subfacies, the highest grade subfacies of the greenschist facies. Hornblende-bearing schists also can be of this subfacies or can belong to the lowest grade subfacies of the almandine-amphibolite facies.

In the Ono quadrangle the outcrop area of the Abrams Mica Schist and Salmon Hornblende Schist is bounded by serpentinite along its northeastern margin. This contact is not exposed but generally may be located within 50 feet. The very irregular pattern of the contact and its discordance with the foliation of the metamorphic rocks indicate the serpentinite intruded the metamorphic complex.

On the northeastern side of the serpentinite body three selvages of metamorphic rocks partially separate the serpentinite from the granitic rocks. In the southeastern selvage, the metamorphic rocks up to 400 yards from the batholith have undergone contact metamorphism and gneissification in the contact zone; along Doby Creek the rocks are also fractured and injected by batholithic material. The rocks in the northwestern selvage are similar, but pyroxene-garnet skarn occurs locally within the gneissic rocks.

In the French Gulch quadrangle Albers mapped similar gneiss on both sides of the serpentinite; he suggested these rocks were derived at least in part from the Abrams Mica Schist and Salmon Hornblende Schist. He also believed they could have been derived, in part, from Copley Greenstone and Balaklala Rhyolite. In the Weaverville quadrangle Irwin (1963) mapped gneiss only to the east of the serpentinite. He thought this gneiss probably was derived chiefly from the Bragdon and Copley Formations, and he considered the rocks west of the serpentinite to be Abrams Mica Schist and Salmon Hornblende Schist.

On a small scale the structure of the metamorphic rocks is quite complex. Many tight asymmetrical folds are present, ranging from microscopic size to about 12 inches from crest to crest. Those axes that could be measured are oriented east-west, but the overall structure could not be ascertained.

No fossils were found in these rocks in the Ono quadrangle and no fossils have been found elsewhere in the outcrop area. Field relations in the northwest part of the quadrangle indicate that these rocks are overlain unconformably by the Bragdon (?) Formation of possible Devonian or Mississippian age. J. P. Albers has found fragments of similar schists in the Copley Greenstone of possible Devonian age (Irwin, 1960b, p. 20).

Copley Greenstone

A small, poorly exposed, tongue-shaped mass of amphibolite schist and hornfels in the northeast corner of the Ono quadrangle is the southern extension of a large body of Copley Greenstone mapped by Kinkel *et al.* (pl. 1) and Albers (pl. 1). The nomenclature of these papers is used in the present report. The Copley Formation was named by Diller (1906, p. 2).

North of the Ono quadrangle the Copley Greenstone is composed of interlayered metamorphosed volcanic flows, tuffs, and agglomerates (Kinkel *et al.*, p. 11). In the Ono quadrangle these rocks have been metamorphosed by the Shasta Bally batholith to dense, dark-green, fine-grained amphibolite schist and hornfels. The schist has a nematoblastic texture and is composed of amphibole and plagioclase with accessory iron minerals. The hornfels has granoblastic texture and is composed of plagioclase and hornblende with accessory zircon and iron minerals.

No fossils have been found in the Copley Greenstone in the Ono quadrangle or elsewhere. The oldest reported datable fossils in the Klamath Mountains area are from the Kennett Formation near Shasta Lake. These fossils indicate a probable Devonian age for at least part of the Kennett Formation (Kinkel *et al.*, p. 37–38; Albers and Robertson, p. 15–16). The Kennett Formation is underlain by the Balaklala Formation and the Copley Greenstone. The age of the Copley is uncertain; it is probably Devonian or pre-Devonian.

Bragdon (?) Formation

Slate and conglomerate south of the junction of Jerusalem Creek and the North Fork of Cottonwood Creek are correlated lithologically with the Bragdon Formation. Hinds (p. 9) noted this occurrence of the Bragdon.

Hershey (p. 236) first used the name Bragdon Slate for a series of thin bedded black slates and thick bedded "blue" quartzites with "its heaviest development in the Trinity mountain (the bulk of which it forms) between the high mountains east of Trinity Center and the vicinity of Lewiston", Trinity County. North of the Ono quadrangle, in the West Shasta copper-zinc district, Kinkel *et al.* (p. 39) said the Bragdon Formation consists of ". . . interstratified shale, sandstone, grit, conglomerate, and a small amount of rhyolitic tuff, and at one locality contains a small flow of mafic lava. Beds of shale make up more than 75 percent of the formation."

In the Ono quadrangle, slate probably makes up about 90 percent of the unit. The slate is tan or light gray on weathered surfaces; freshly broken surfaces are black. Thin beds of grit and conglomerate comprise the rest of the formation. Clasts in these coarser grained beds are mostly granule or pebble size and are mainly light- and dark-colored chert. The grits and conglomerates are almost entirely deformed to stretched-pebble conglomerates. The Bragdon (?) Formation is so poorly exposed and deformed that its thickness in the Ono quadrangle could not be ascertained.

The relationship between the Bragdon (?) Formation and adjacent schist is not clear. Irwin (1963, 1964) has suggested that the structure of the pre-Tertiary strata of the Klamath Mountains be interpreted as a series of successively overlapping thrust

plates, with post-faulting emplacement of ultramafic rocks along the fault surfaces.

The differences in the degree of metamorphism between the Bragdon (?) slate and the adjacent schist, and the configuration of the exposure of Bragdon (?) are most easily explained by considering the Bragdon (?) an outlier of a thrust in a tectonic setting such as proposed by Irwin. Further, the occurrence of serpentinite along part of the contact is in keeping with Irwin's interpretation.

No fossils were found in the Bragdon (?) Formation in the Ono quadrangle. The few fossils found in the Bragdon north of Redding indicate a Devonian or Mississippian age (Diller, 1905; 1906, p. 3; Kinkel *et al.*, p. 41; Albers and Robertson, p. 18).

Shasta Bally Batholith

The Shasta Bally Batholith (Hinds, p. 105) is exposed in the north-central part of the quadrangle. It is composed of medium- to coarse-grained hypautomorphic-granular quartz diorite, with diorite and gabbro along the western edge of the body.

The quartz diorite is composed of about 50 percent plagioclase (An_{20}–An_{40}); biotite is the predominant mafic mineral in the eastern part of the outcrop area, but hornblende is predominant in the western part. Orthoclase is a common minor mineral. Magnetite, zircon, and apatite are primary accessory minerals; calcite, epidote and chlorite are secondary minerals. The chlorite is commonly seen as replacement of biotite.

The hornblende diorite and gabbro differ from the quartz diorite in that they contain more hornblende, less quartz, and plagioclase of higher anorthite composition ($An_{50}\pm$). In some of the more basic rocks quartz is absent and hornblende is the sole mafic mineral.

Pegmatite and aplite dikes are found throughout the exposures of the batholith in the Ono quadrangle, but are not abundant. Individual dikes range in thickness from 2 to 12 inches, and are composed of quartz, plagioclase (An_{18-20}) and orthoclase; muscovite and magnetite are accessory minerals.

Near the western contact of the batholith a zone up to 400 feet wide contains numerous inclusions of altered country rock from a few inches to a foot across. In places the concentration of these inclusions gives the rock the appearance of an intrusive breccia. Flattened inclusions from 3 to 12 inches long occur throughout the intrusion, but are not abundant in the Ono quadrangle. These inclusions are finer grained, darker, and richer in hornblende than the quartz diorite.

The age of the Shasta Bally Batholith has been determined by both the Larsen (lead-alpha) method (Kinkel *et al.*, p. 50) and by the potassium-argon method (Curtis *et al.*, p. 5). The date obtained by the Larsen method is believed erroneous. The potassium-argon date was recently revised by Kulp (p. 1113), who used the decay constant $\lambda e = 0.584$. He gives the most probable age as 127 ± 4 m.y. Since the relative age of the batholith can be ascertained with fair accuracy in the standard geological column, a tie between absolute and relative chronologies is possible.

The lower age limit for the batholith has been discussed by Kinkel *et al.*; Curtis *et al.*; Faul; Kulp; Howarth; and Casey, and based on rock relations it is established as post-Bajocian (post lower Middle Jurassic).

The upper age limit for the batholith has also been discussed by these authors, especially by Casey. Our comments pertain only to the dating of the upper age limit.

Imlay and Popenoe *et al.* (p. 1506) have discussed the age of ammonite faunas found in the Cretaceous rocks resting unconformably on the batholith in the vicinity of Ono, California. They concluded that the lowest ammonite zone in this area is the *Hertleinites aguila* zone, which they placed in the upper Hauterivian.

Casey (p. 322) believes that this zone could as easily be lower Barremian and that a Barremian age would give ample time for the batholith to have been unroofed after emplacement in Valanginian time. Casey bases his argument for a Barremian age on the occurrence of *Simbirskites broadi*, reported by F. M. Anderson (p. 155) in his Hamlin-Broad zone, which is assumed to be a valid biostratigraphic zone below the *H. aguila* zone. In fact, it is not a zone. We believe that the fossils from Anderson's locality (California Academy of Sciences locality 113) and, hence, his Hamlin-Broad zone were collected in the general area at the head of Mitchell Creek and represent at least four fossiliferous horizons. We are not sure of this since most specimens were donated to the Academy by two amateur collectors, Hamlin and Broad.

The only specimen of *Simbirskites* for which the stratigraphic position is known was identified by Murphy (in Popenoe *et al.*, p. 1507) with the paratype of Anderson's *Simbirskites broadi*. Imlay (p. 209) has assigned Anderson's paratype to *Simbirskites lecontei* (Anderson); thus, the stratigraphic position of *Simbirskites broadi* is unknown. Since the two main points in Casey's argument are thus demolished, Imlay's dating of the *Hertleinites aguila* zone as upper Hauterivian seems equally as plausible as Casey's. In addition, there was continuous sedimentation in the region for a considerable time before advent of the *Hertleinites* fauna, while about 9,000 feet of *pre-Hertleinites* sediments accumulated in the adjacent Chanchelulla Peak quadrangle. The strand line was continually moving toward the site of the batholith during this time, indicating a regional subsidence. We need time, therefore, not only to emplace the batholith at depth sometime after the Bajocian, but also to unroof it, reverse the process of uplift, and accumulate approximately 9,000 feet of sediments before late Hauterivian time.* It seems logical to infer a Late Jurassic rather than an Early Cretaceous age for the crystallization of the batholith.

Serpentinite

A large, irregular, elongate serpentinite body is adjacent to the southwest margin of the Shasta Bally

* During the 1968 field season, more evidence was found supporting correlation of the *Hertleinites aguila* zone with the lowest Barremian. This finding does not invalidate the present argument, since there is still plenty of room for many earlier zones below the *Hertleinites aguila* zone.

batholith and in general separates the batholith from the metamorphic rocks to the west. Several smaller bodies occur in the metamorphic rocks near the main outcrop. The serpentinite is more resistant to weathering and forms characteristic brown, rubble-covered ridges that are higher than the adjacent terrain and support a sparser vegetation.

Along the Musselbeck Dam road, near the Ducket Creek crossing, an elongate body of serpentinite is surrounded by quartz diorite, suggesting the serpentinite is a dike, but the contact relations of the two rocks are not exposed. According to Irwin (1960b, p. 58), however, "The available data suggest that the ultramafic and granitic rocks of the Klamath Mountains were emplaced during the same general interval of time [Late Jurassic] the ultramafic rocks preceding the granitic rocks."

The fresh rock is light green to black, generally fine-grained and massive, and consists mostly of densely packed, short, randomly oriented fibers of antigorite, with a few thin seams of fibrous chrysotile. Texture in a few specimens suggests that the antigorite is mainly a pseudomorph after olivine. The primary constituents, olivine and pyroxene, have undergone nearly complete replacement and occur only as small irregular masses surrounded and penetrated by antigorite. Small grains of magnetite are always present.

CRETACEOUS ROCKS

The Cretaceous sequence consists of marine sedimentary rocks of Hauterivian through Turonian age. Predominant lithologies are mudstone, siltstone, and sandstone. Conglomerate units are prominent in some parts of the sequence but constitute a small fraction of the total volume of rock. Limestone occurs in concretionary masses, lenses, or beds of possible postdepositional origin.

A summary of lithologic and biostratigraphic classifications used in this paper is presented in figure 2. Lithologic nomenclature is after Murphy *et al.* (1964); biostratigraphic nomenclature is from Popenoe *et al.* (pl. 1). The history of geological studies in this area may be found in Popenoe *et al.* and Murphy.

Budden Canyon Formation

The entire Cretaceous sequence in the Ono quadrangle and the adjacent Chanchelulla Peak quadrangle to the west is approximately 22,000 feet thick along the Budden Canyon-Dry Creek line of section (A-A', pl. 1) and is considered a single formational unit, the Budden Canyon Formation (Murphy *et al.*, 1964). The formation is predominantly dark gray, massive mudstone and siltstone. Lenticular sandstone, conglomerate, and pebbly mudstone units are concentrated in some stratigraphic intervals. These coarse clastic rocks form outcrop belts that divide the Budden Canyon Formation into seven members. Members or mappable units consisting almost entirely of conglomerate or sandstone have been delineated on the geologic map (pl. 1) by conventional contact lines. But, since no continuous mappable boundaries exist between the other members, they are indicated on the geologic map by the concentrations of mapped beds and by slight color changes. The color boundaries are not formal mappable contacts but merely outline areas of concentration of sandstone and conglomerate beds. The cartographic representation of these rocks has been discussed previously by Murphy *et al.* (1964).

RECTOR MEMBER

The basal contact of the Lower Cretaceous strata in the Ono district is clearly exposed from a point on the Ono-Igo road in the northeast part of the quadrangle to the west edge of the quadrangle near Ogo Station. Along this contact, sandstone, conglomerate, and pebbly mudstone rest unconformably on the igneous and metamorphic rocks of the Klamath Mountains complex, and dip about 20° southeast away from the Klamath Mountains.

The 20 to 400 feet of sandstone, conglomerate, mudstone and pebbly mudstone that occur above the unconformity at the base of the Cretaceous section were named the Rector "formation" by Murphy (p. 2103) from exposures along Rector Creek, a small tributary to the North Fork of Cottonwood Creek at Ono. This unit was later restricted (Murphy *et al.*, 1964) to include only the conglomerate lenses along the contact with the basement complex. The maximum thickness measured is 200 feet.

The Rector Member is interpreted as the initial deposits of the transgressing Early Cretaceous sea. The deposits accumulated in topographically low areas of the pre-Budden Canyon Formation terrain and are very lenticular. On the North Fork of Cottonwood Creek where the exposures are good (SE ¼ Sec. 18, T. 30 N., R. 7 W.), the conglomerate beds strike into the unconformity with the basement rocks at angles greater than 20°.

These beds are true basal conglomerates with the clasts composed of the same lithologic type—granitic and metamorphic rocks and serpentine—present in the local crystalline basement rocks. In this respect these beds differ from the other conglomerate beds in the Budden Canyon Formation, which are derived from rocks not represented in the local basement terrain.

Although no fossils have been found in conglomerate in the Ono quadrangle, the immediately overlying rocks contain fossils of late Hauterivian age. The conglomerates are probably not much older.

OGO MEMBER

The Ogo Member (Murphy *et al.*, 1964) includes beds between the Rector Member (or the basement contact where the Rector is absent) and the Roaring River Member (or the Chickabally Member where the Roaring River Member is absent). In the Ono quadrangle, the Ogo Member is composed of massive siltstone and mudstone and thick and thin bedded, fine-grained to granule sandstones. In the Chanchelulla Peak quadrangle to the west, mappable conglomerate lenses are also present. The complete Ogo Member ranges from about 850 feet thick near Ono to nearly 10,000 feet thick in the Budden Canyon-Dry Creek section, mostly in the Chanchelulla Peak quadrangle. At least the upper 9,000 feet in the latter sequence are composed of thin-bedded sandstone and interbedded mudstone.

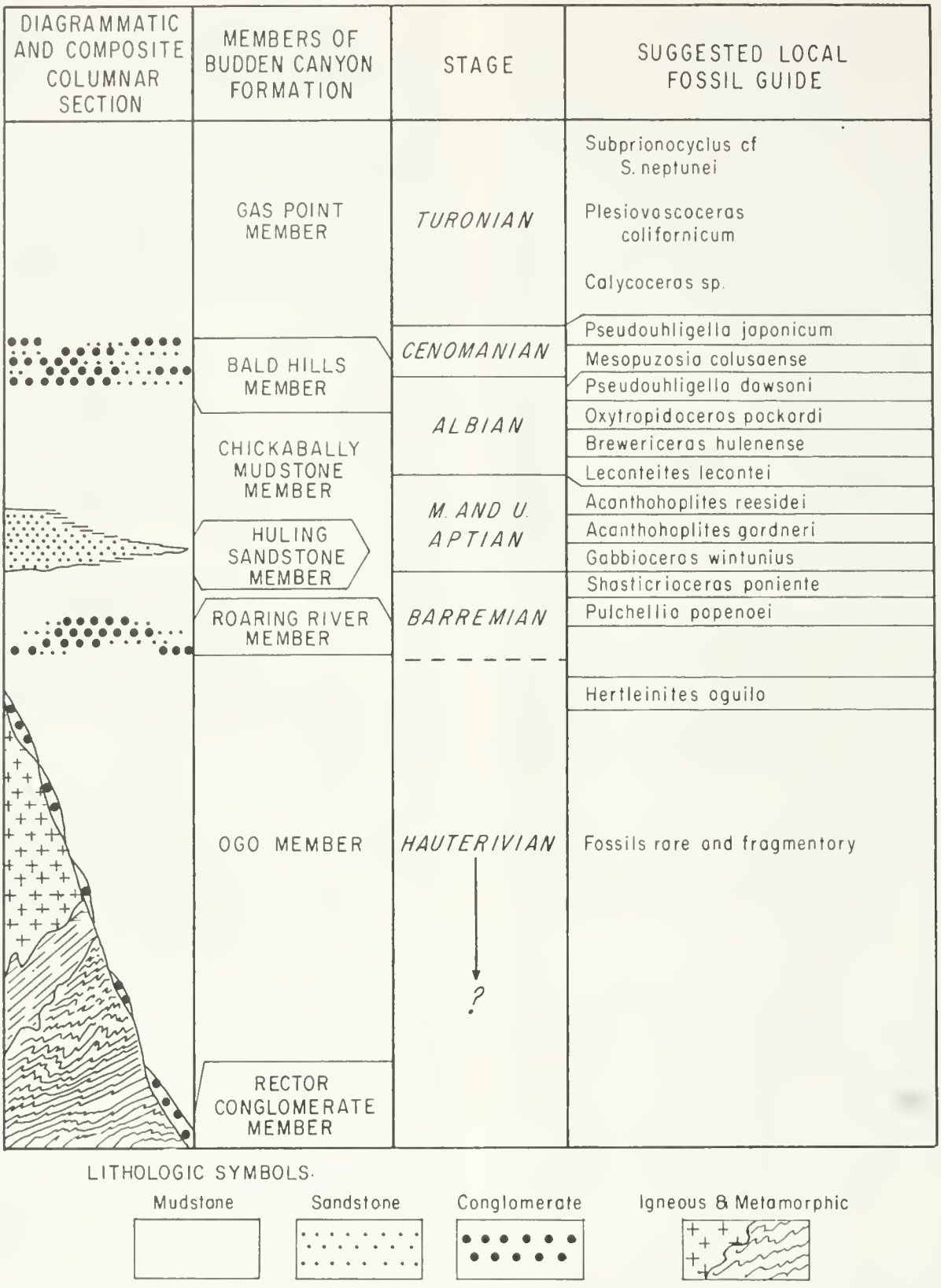

Figure 2. Summary of lithostratigraphic and biostratigraphic classifications used in the Ono quadrangle.

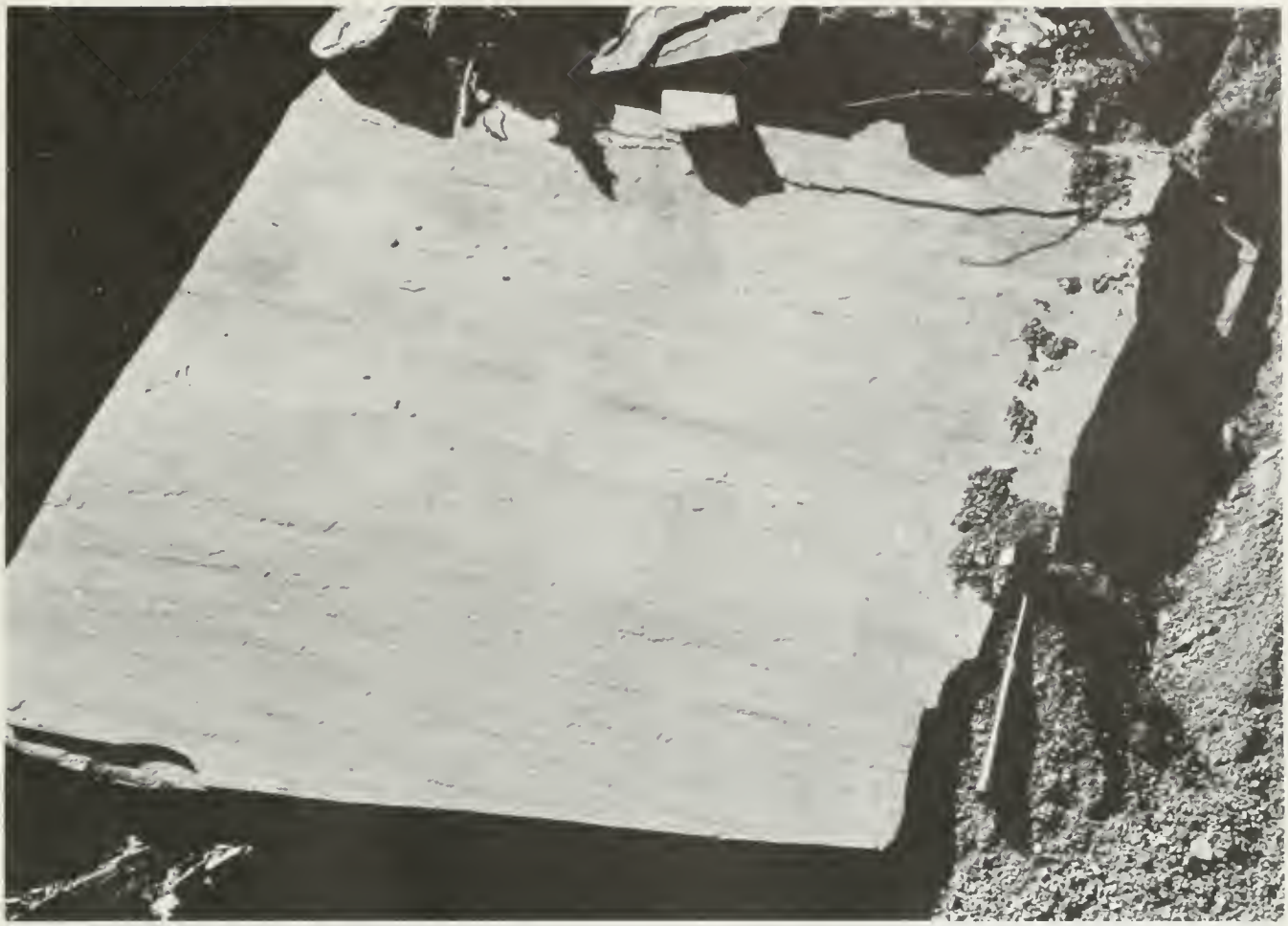

Photo 1. Parting lineation, the commanest current structure encountered in the Budden Canyon Formation, is especially well developed in the Ogo Member, as here, near Dry Creek, Tehama County. Parting lineation generally parallels other current structures.

Photo 2. Substratal lineations show slight angular deviation from parting lineation of the same bed. Wells Creek, upper Ogo Member, Tehama County.

Photo 3. Intrastratal folding, Ogo Member, Wells Creek, Tehama County. Usually accompanied by thickening of the folded bed. This kind of structure is interpreted as a slump structure, in which the movement of the slumped mass has not been great but has attenuated some parts of beds while developing accordion-like folds in other parts.

Where the Ogo Member is in contact with basement, as at Huling Creek, the sandstones appear to grade into the underlying quartz diorite. Deposition of the Rector and Ogo Members was continuous, and, in many places, there is a transition from conglomerate to sandstone and finally to mudstone.

In the northern part of the quadrangle, the Ogo Member typically has a lower unit of 50 to 200 feet of thick bedded, massive or laminated, fine-grained to granule sandstone containing abundant biotite and feldspar. This is followed by a mudstone unit with limestone concretions and minor amounts of thinly bedded sandstone which ranges from 50 to several hundred feet in thickness.

The lower units of the Ogo Member thin from west to east, reflecting the transgressive basement contact. Just south of the road at Ogo Station the lower part of the Ogo Member is mudstone, but this mudstone unit is not present where the North Fork of Cottonwood Creek cuts the basement contact and exposes a thick sequence of thinly interbedded mudstone and sandstone. Farther east, at Ono, most of the lower succession present at Ogo Station is absent.

Above the lower units is a sequence of thin- to medium-bedded, mostly fine-grained sandstone alternating with slightly thicker beds of mudstone. This sequence is as much as 9,000 feet thick along the Budden Canyon section, mostly west of the Ono quad-

rangle. Sandstone beds in this sequence are commonly laminated, and many have other sedimentary structures resulting from currents, penecontemporaneous deformation, and animal activity.

Parting lineation (Crowell, 1955, p. 1361) is the most common sedimentary structure. Other structures include flute casts; groove casts and other linear markings; cross lamination, commonly associated with interference ripple marks; oriented plant fragments; and sinuous burrows exposed on the lower bedding surfaces. Directional measurements of parting lineation, substratal flow marks, and cross lamination indicate a general current direction to the south or southeast (fig. 3).

Many beds in the upper part of the sequence show intraformational deformation, disrupted bedding, and low-angle contacts with overlying beds. Numerous sandstone beds are abruptly lenticular due in part to pulling apart of bedding during slumping and downslope accumulation of disrupted material. The surfaces of such beds are irregular or corrugated and the internal laminae distorted. Fragments of more completely disrupted sandstone beds have been rolled and incorporated in thicker beds of mudstone. Large, angular, disoriented, commonly contorted blocks of sandstone are included in some mudstones; lamination in these mudstones has been obliterated. Similar features in pebbly mudstones have been described by Crowell (1957, p. 997–998). In other fine-grained beds laminae are highly contorted, but not completely disrupted.

Photo 4. Minor angular discordance between sandstone bed and underlying siltstone beds. Such relations are common in the Budden Canyon Formation. They probably result under conditions of sedimentation where the slope is fairly steep and considerable slumping occurs. Wells Creek, Oga Member, Budden Canyon Formation.

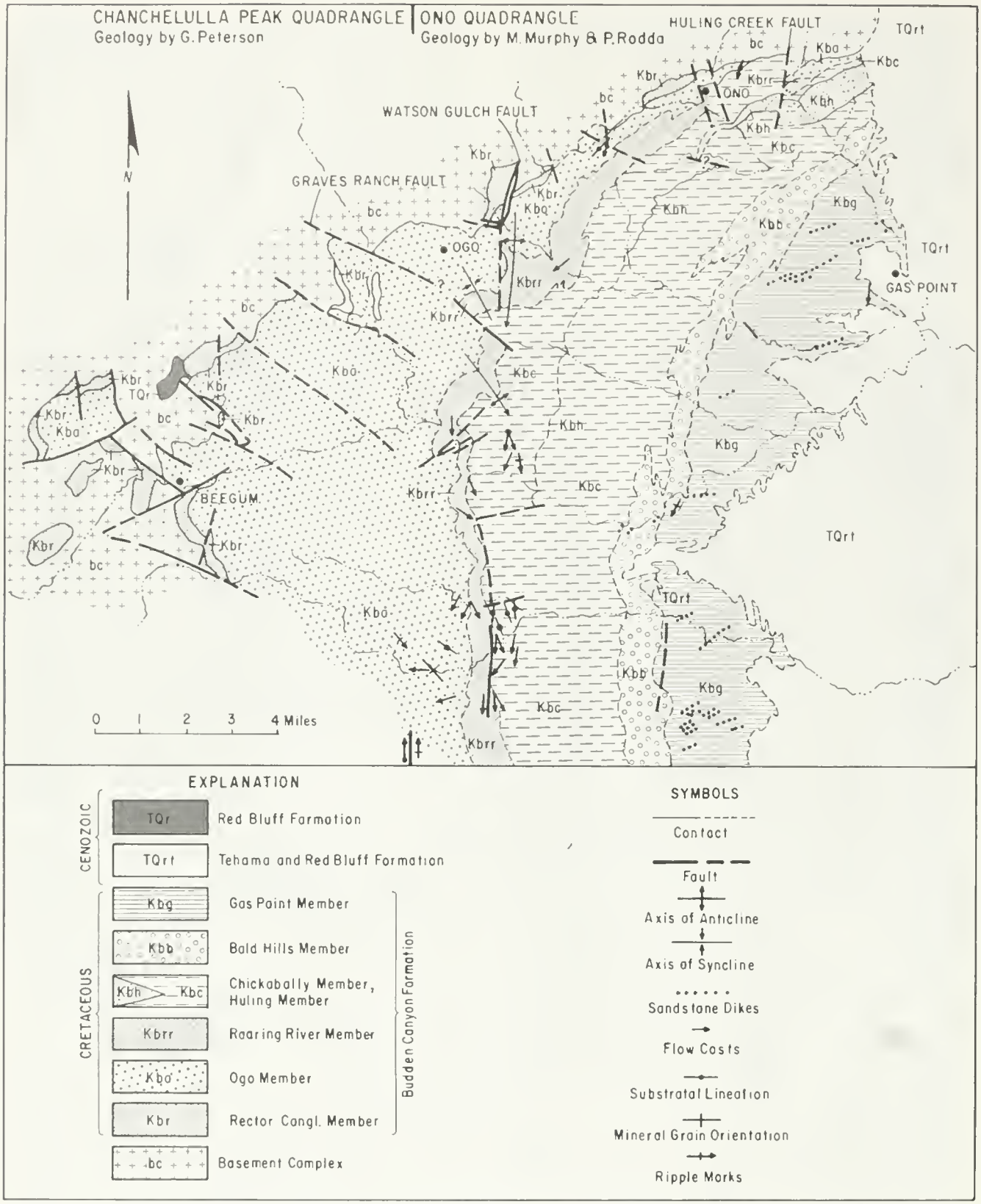

Figure 3. Fault pattern, lithologic units, and current lineations in the Ono and Chanchelulla Peak quadrangles.

Photo 5. Divergence of beds around twisted, isolated and unoriented sandstone blocks in a mudstone matrix, Ogo Member, Wells Creek, Tehoma County. Complex folding is also present in the mudstone beds, but it cannot be seen in the picture. This type of structure is interpreted as a slump structure in which the sandstone beds have been considerobly pulled apart and convoluted by being rolled along within the mass.

The Ogo Member is of Hauterivian age. Common or important fossils that have been collected from this member by the writers include:

Ammonites
- *Simbirskites lecontei* (Anderson)
- *Lytoceras auleum* Anderson (most common ammonite)
- *Hertleinites aguila* (Anderson)
- *Hypophylloceras* sp.
- *Shasticrioceras* sp.

Pelecypods
- *Nucula gabbi* Stanton
- *Parallelodon breweriana* (Gabb)
- *Inoceramus ovatoides* Anderson
- *Entolium operculiformis* (Gabb)
- *Plicatula variata* Gabb
- *Pholadomya altaumbonata* Anderson

Gastropods
- *Potamides diadema* Gabb

Many other fossils, including ammonites, belemites, pelecypods, gastropods, foraminifera, and plants, have been collected from these beds, but they have not yet been described or adequately identified. Several of these are listed by Murphy (p. 2114).

Fragmentary plant remains are especially abundant. The most common identifiable remains encountered in this study are fern pinnules and *Dioonites* sp. A number of other plants were described long ago by Fontaine (in Ward). Chandler and Axelrod recently described one of the earliest unquestioned fossil angiosperms, *Onoana californica*, from a specimen collected by Murphy and Rodda in the upper part of the Ogo Member.

Photo 6. Transverse fault, north bank of Middle Fork of Cottonwood Creek, separates Ogo Member (right) from Roaring River Member (left).

ROARING RIVER MEMBER

This unit, originally proposed as a tongue by Murphy (p. 2111), is retained for the swarms of lenticular conglomerates and thick-bedded, fine- to coarse-grained, feldspathic sandstones that are mapped from the North Fork of Cottonwood Creek to the southern boundary of the Ono quadrangle. These conglomerates and sandstones form an outcrop belt topographically higher than the less resistant mudstones and sandstones stratigraphically above and below. The thicker units of the Roaring River Member generally are well exposed; most thin units are exposed only in stream cuts and are impossible to map between these exposures. The thickness of the member along the type section on Roaring River * (Secs. 30, 29, 32 of T. 30 N., R. 7 W.) is about 850 feet.

In the southern part of the quadrangle the Roaring River Member is distinguished from the underlying alternating thin beds of sandstone and mudstone by an increase in thickness of the sandstone beds and the presence of lenticular conglomerate beds. No mappable boundary exists; conglomerate and sandstone beds are lenticular and the vertical change is transitional. In the northern part of the area the section underlying this member has virtually no sandstone interbeds, and there is an abrupt transition between thickly bedded sandstone and conglomerate above and mudstone below.

The conglomerate unit stratigraphically below the Huling Member on Huling Creek possibly is within the same stratigraphic interval as conglomerates of the Roaring River Member, but this is not yet substantiated. This conglomerate was excluded from the Huling Member so that this possibility would not be

* Several names on the 1952 Ono 15′ quadrangle do not agree with local usage or with those used in the geologic literature before publication of the topographic map. For example, Wilson Creek is substituted for Roaring River, Roaring River is substituted for Mitchell Creek, Ilee Creek is substituted for Alderson Gulch, and no name is on the map for the Ilee Creek of local usage. Huling Creek is misspelled "Hulen" in the geologic literature. With the exception of Bee Creek we have changed the topographic base-map names to conform with the usage in the geologic literature.

masked by our nomenclature (Murphy *et al.*, 1964). The conglomerate was originally included in the Huling tongue of Murphy.

Conglomerates of the Roaring River Member are composed typically of clasts of porphyritic volcanic rocks, dark gray to black chert, and minor amounts of orange weathering limestone and calcareous siltstone, sandstone, and granitic rocks. Volcanic and chert clasts are mostly well rounded; sedimentary clasts are mostly subangular or subrounded. Limestone clasts tend to be concentrated in stringers where they predominate or are the only type of clast present.

Bedding is absent or poorly developed in the conglomerates, but a fabric in which clasts are oriented parallel to the bedding is present in many places, and in some outcrops imbrication of the clasts is well developed.

The sandstones exhibit many sedimentary structures, such as substratal markings, parting, lineation, ripple marks, oriented plant fragments, and animal burrows. Other features, such as intrastratal deformation and disruption, and local abundance of angular fragments of mudstone, indicate slope conditions favorable to slumping and sliding.

No identifiable fossils have been found in the Roaring River Member.

CHICKABALLY MEMBER

The Chickabally Member (Murphy *et al.*, 1964) includes mudstone and thin-bedded sandstone and limestone beds lying between the Roaring River Member and the Bald Hills Member. Along the type section on Roaring River, in Secs. 32 to 35 of T. 30 N., R. 7 W., the lower 400 to 600 feet of beds are mudstone with thin, fine-grained, feldspathic sandstone interbeds, and limestone concretions. Vertically this changes gradually to mudstone with few thin sandstone interbeds and limestone in concretions, lenses, and thin beds. The limestone is silty and commonly has a yellow-orange weathered surface.

The lower part of the member is about 900 feet thick, and is separated from the upper part of the member by a 10-foot bed of sandy and pebbly mudstone which is interpreted as an extension of the sandstone of the Huling Member. The 2600 feet of the Chickabally Member above this bed are characterized by siltstone and mudstone with few sandstone beds, and with light-gray-weathering, finely crystalline, ellipsoidal or irregular-shaped, dark gray limestone concretions. In the upper 200 feet of the member, however, the concretions are predominantly disc-shaped, medium gray, silty limestone that is commonly bright orange on weathered surfaces.

Several important pebbly sandstone and pebbly mudstone marker beds occur in the northern outcrops of the member and connect the fossiliferous sections on the two branches of Huling Creek (Murphy, p. 2110). These marker beds pinch out toward the southwest and are not present on the North Fork of Cottonwood Creek.

Several sandstone beds show well developed flute casts, and parting lineation is common in the lower sandstone interbeds along Dry Creek where it crosses Vestal Road. These directional features indicate southward flowing currents at the time these rocks were deposited.

The upper part of the Chickabally Member below the extension of the Huling Member contains the *Shasticrioceras poniente* fauna of Barremian age (Murphy, p. 2113–2114; Popenoe *et al.*, p. 1508). In the lower part is a largely undescribed fauna of which *Inoceramus ovatoides* and *Lytoceras* n. sp. are common fossils.

Northeast of the North Fork of Cottonwood Creek the lower Chickabally Member lies directly on the Ogo Member and contains a *Hertleinites aguila*-zone fauna; units of the Roaring River Member do not extend into this area, with the possible exception of the conglomerate unit below the Huling Member on Huling Creek (see discussion of Roaring River Member).

The upper part of the Chickabally Member, about 1200 feet thick along the exceptionally fossiliferous Huling Creek section, ranges in age from Aptian through late Albian in the northern outcrops and contains the faunas of the *wintumius*, *gardneri*, *reesidei*, *lecontei*, *hulenense*, *packardi*, and *hulenanum* zones (Murphy, p. 2114–2119; Popenoe *et al.*, p. 1508–1510). On Dry Creek, in the southern part of the quadrangle, the upper beds of this member contain *Desmoceras (Pseudouhligella) japonicum*, *Mesopuzosia colusaense*, and *Marshallites* sp., a fauna of Cenomanian age.

The two parts of the Chickabally Member are recognized easily on the basis of lithology and position in sequence as far south as Big Salt Creek. Farther south in the Ono quadrangle the lithologic differences are not marked enough to permit separate recognition.

HULING MEMBER

This unit, originally proposed as the Huling tongue by Murphy (p. 2111), was redefined and restricted by Murphy *et al.* (1964). The redefined unit is predominantly poorly sorted sandstone with minor mudstone and conglomerate lenses in the lower part. The member has a maximum thickness of about 850 feet along Huling Creek, the type section, in the northeast corner of the Ono quadrangle.

Along Huling Creek the lowest unit in the Huling Member is composed of interbedded sandstone and conglomerate. The conglomerate beds are 5 to 10 feet thick and contain well-rounded, predominantly porphyritic volcanic clasts averaging about 2 inches in diameter. The sandstones are thinly and regularly bedded at the base, but become thickly bedded and are increasingly fine-grained toward the top of the unit.

The next 200 feet of section, starting at the upper end of the gorge along Huling Creek, consist of a well indurated, massive, non-bedded, feldspathic sandstone that grades vertically into the flaky weathering, thickly bedded sandstone unit that comprises the upper 500 feet of the Huling Member. This upper unit contains a zone of abundant sandstone concretions; in places the unit resembles a conglomerate. Fossils of the *Gabbioceras wintumius* zone (Aptian) have been collected from the upper 200 feet of these beds. These

Photo 7. Flute casts on prominent sandstone bed in the Chickabally Member, Dry Creek, Tehama County. Half-dollar indicates size.

beds also contain several lenses from which heavy shelled pelecypods including *trigoniids* have been collected.

The section exposed along the east fork of Huling Creek is similar to that on Huling Creek. West of the Huling Creek fault the Huling Member is much thinner and contains no conglomerate.

About 150 feet of this sandstone unit is exposed in the bed of the North Fork of Cottonwood Creek. Belemnites and much woody material including branches up to 10 inches in diameter have been collected here. The ammonite *Tropeum percostatum* (Gabb) occurs 15 feet above the base of the unit here.

The Huling Member thins progressively to the southwest, and can be traced almost continuously to Roaring River. Farther south it is recognized in isolated outcrops on Aiken Gulch, Wiley Flat, probably on Fiddler Creek, and on Big Salt Creek. At Bee Creek the unit is about 10 feet thick and is truncated by a northwest-trending fault. Several sandstone beds are present on the opposite side of the fault, but only one is fossiliferous, and it contains essentially the same fauna as on the northeast side of the fault. To the south of the fault, in the Bald Hills, the ammonite *Tropeum percostatum* was collected about 17 feet above the base of this bed, the same level at which this fossil occurs on the North Fork of Cottonwood Creek.

From Bee Creek (the "Alderson Gulch" of F. M. Anderson) to Roaring River, this bed is a distinctive, easily recognized, fossiliferous, pebble and cobble mudstone without internal structure or orientation of the clasts. At some localities it grades laterally to poorly sorted pebbly sandstone. This is doubtless the bed Anderson (p. 65) named the "Barr zone" or "Barr conglomerate". The fauna of this bed differs from beds above and below in the lack of ammonites, in the abundance of belemnites (the most abundant fossil), gastropods, pelecypods (especially *Entolium*), and wood fragments, and the presence of the brachiopod *Cyclothyris averilli* (Anderson). The bed probably was deposited as a submarine slide or mudflow which transported animals and plant material from a different environment. At Wiley Flat, where the bed is a belemnite conglomerate, the belemnite guards are oriented

parallel to one another, suggesting subsequent current action.

Locally, in the northern part of the quadrangle, slightly angular relations between the Huling Member and underlying beds plus lithologic and marked faunal changes suggest an unconformity. Early Aptian fossils have not been recognized, possibly because the fauna in the upper part of the *Shasticrioceras poniente* zone is markedly provincial. The possibility exists that these beds may be lower Aptian, although all authors have previously placed them in the Barremian.

BALD HILLS MEMBER

This unit was first described as the Bald Hills Formation by Murphy and Rodda (p. 835–838) and was subsequently redefined and reduced to member status by Murphy *et al.* (1964). The Bald Hills Member is composed of arkosic sandstone, conglomerate, and pebbly mudstone lenses and beds concentrated in a predominantly mudstone and siltstone section. It forms an outcrop belt topographically higher than mudstones of the underlying Chickabally Member or the overlying Gas Point Member, and is covered by oak and manzanita, in contrast to the grass covered slopes of the mudstone units. This member has been traced from the type area in the Bald Hills to the southern boundary of the quadrangle. At the type section along Crow Creek the Bald Hills Member is 1870 feet thick.

Conglomerates in the Bald Hills Member contain clasts similar in composition, size, and roundness to those in the Roaring River Member. The average cobble is about 2 inches in diameter, well rounded, and set in a matrix of medium- to coarse-grained sandstone or sandy mudstone. The majority of the clasts are well-rounded andesite porphyry, chert, or subangular to subrounded, orange-weathering silty limestone. Few sedimentary structures were noted other than bedding, parallel orientation of the clasts, and cut-and-fill. Clasts of limestone in the lowest conglomerate bed on the North Fork of Cottonwood Creek contain fossils derived from older Cretaceous rocks (Murphy and Rodda, p. 838).

Photo 8. Two *Pseudouhligella* in a clast in the lower conglomerate of the Bald Hills Member, North Fork of Cottonwood Creek. Note the mudstone matrix in the lower left corner and above the sandstone clast. Also note the different orientations of the two sandstone clasts and the virtual lack of contract of the clasts with one another. Clasts of this type prove the reworking of almost contemporaneous, lithified sediments.

Photo 9. Conglomerate bed in the Bald Hills Member, Middle Fork of Cottonwood Creek. The lithology and texture of this bed contrast strongly with the bed on the North Fork of Cottonwood Creek; clasts from the latter bed appear in photo 8. The beds are not lateral equivalents.

The age of the Bald Hills Member ranges from late Albian through Cenomanian. The reasons for this assignment have been detailed previously (Murphy and Rodda, p. 838); a list of the fossil cephalopods and gastropods from this unit is given in that paper. The most common fossils are *Cucullaea truncata* Gabb and various species of *Desmoceras* (*Pseudouhligella*).

GAS POINT MEMBER

The Gas Point Member is the uppermost Cretaceous unit of the Budden Canyon Formation in the Ono quadrangle. The unit was first proposed in a dissertation by Rodda (p. 30), and later formally by Murphy *et al.* (1964). The Gas Point Member lies above the Bald Hills Member, and has been mapped from the northern limit of the Cretaceous outcrop to the southern boundary of the quadrangle. Since the Gas Point Member has been mentioned only briefly in previous literature, a fuller account of its character is given here.

The Gas Point Member, which derives its name from the now abandoned hamlet of Gas Point, has a maximum thickness of 3770 feet, and is divided into three parts in the type section on Crow Creek. The lower and upper parts are composed of siltstone and mudstone, and the middle part contains interbedded sandstones. The lower part is 2500 feet thick, and in the type area is composed of gray siltstone and mudstone containing up to 10 percent limestone nodules, lenses, and thin beds. The limestone occurs as three distinct types: (1) dark gray to black limestone nodules, up to three feet across, and thin lenses and beds, less than a foot thick; (2) light to dark gray septarian concretions with a wide range of sizes, but averaging more than a foot in diameter; (3) light gray to tan, orange weathering, discoidal nodules, lenses and thin beds usually less than six inches thick. Types (1) and (3) occur throughout the member although the orange weathering limestone is much more common.

Type (2) is essentially confined to an interval 1000 to 1400 feet above the Bald Hills Member. A few large specimens were also found on Crow Creek in the upper 50 feet of the member. Thin, fine-grained, arkosic sandstone beds occur throughout the mudstone units, but make up less than one percent of the total.

Mappable beds are virtually nonexistent. However, a narrow belt of fossiliferous, coarse-grained sandstone and sandy limestone-pebble conglomerate beds, below the zone of septarian concretions, crops out discontinuously from Crow Creek to the North Fork of Cottonwood Creek.

The mudstone of the lower part is abruptly overlain by thickly bedded, medium- to coarse-grained, arkosic sandstones. This part of the member is about 670 feet thick on Crow Creek. The section is shown in Table 1.

Table 1. Section of Middle Part of Gas Point Member, Crow Creek

Sandstone, gray, medium- to coarse-grained, flaggy, micaceous, arkosic beds 6 inches to 2 feet thick, separated by equal thicknesses of siltstone and fine-grained sandstone. The amount of sandstone gradually decreases and is less than 10 percent at the top	325 feet
Siltstone and mudstone, dark gray, thick-bedded, massive, with orange weathering limestone nodules and lenses	140 feet
Sandstone, gray, thick-bedded, coarse-grained, micaceous, feldspathic (averaging 1 to 2 feet thick), separated by thin beds of siltstone and fine-grained sandstone (current lineations indicate a southerly current direction)	215 feet
Thickness of middle part of Gas Point Member	680 feet

The dark mudstones of the upper part of the Gas Point Member resemble those of the lower part and have a total thickness of 600 feet. The Gas Point Member is overlain unconformably by the non-marine Tehama (late Pliocene) and Red Bluff (Pleistocene) Formations.

Along the North Fork of Cottonwood Creek, the Gas Point Member ranges in age from Cenomanian to late Turonian. Along Roaring River and Dry Creek, the age range is from late Cenomanian to late Turonian or possibly early Coniacian.

The important ammonites listed in Table 2 have been collected from the mudstone units in the Gas Point Member; no fossils have been found in the middle sandstone unit.

Table 2. Important Ammonites in Mudstone Units of Gas Point Member.

Ammonite	Occurrence
Subprionocyclus of S. neptuni (Geinitz)	Upper mudstone unit
Plesiovascoceras californicum (Anderson)	Middle and upper part of lower mudstone unit
Gaudryceras densiplicatum (Jimbo)	All but lower part of lower mudstone unit in the northern outcrop area
Mesopuzosia pacifica (Matsumoto)	All parts of unit
Calycoceras sp.	Lower part of lower mudstone in Dry Creek area
Eogunnarites n. sp.	Lower part of lower mudstone in the northern outcrop area

Other common fossils in the Gas Point Member include *Glycymeris pacificus* (Anderson), *Cucullaea* n. sp., *Turritella* cf. *T. petersoni* Merriam, *Ringicula* n. sp., and *Trochocyathus* sp.

Sandstone Dikes

The eastern part of the area is notable for being a part of what might be called the "type" area for sandstone dikes. These outstanding features have been well known since Diller's excellent 1889 paper, perhaps the earliest to treat them in detail.

The dikes range in thickness from a fraction of an inch to great walls several feet thick, and in length from a few inches to several miles. The longest one measured in this area was about three miles; Diller has mapped one nine miles long. Hundreds of dikes were observed during the present study, but only the largest and most extensive have been mapped. The average strike of the dikes is N. 70° E., and the average dip is about 82° north. The dikes are one of the more resistant rocks in the area, and may, when parallel to a stream course, form prominent walls as high as 30 feet.

The composition and origin of these dikes were described by Diller and need only be summarized here. The composition of the dike rock is essentially that of the associated Cretaceous sandstones, but the dike rock appears to have little fine-grained matrix and is usually of a lighter color. The rock is made up of feldspar, quartz, biotite, and rock fragments with a calcareous cement. Diller (1889, p. 425–427, 433) has shown that the biotite flakes in the dikes are deformed in a manner that strongly indicates flowage from below, and suggests that the dikes were formed by aqueous injection of sand along fissures associated with faulting. The rocks surrounding the dikes are seldom disturbed, as they might be if the dikes had been semi-solid injections, or if they had been forced into unfractured mudstone. Further evidence for the aqueous injection origin are the small branches of larger dikes, which pinch out vertically. The source of the sand was presumably the underlying Cretaceous units.

In this area most of the sandstone dikes intersect Cretaceous rocks ranging from the middle of the Bald Hills Member to the top of the Gas Point Member. A few have been observed in the lower part of the Budden Canyon Formation near Ono. The dikes do not intersect the Late Cenozoic Tehama and Red Bluff Formations. The time of formation of the dikes can be given only as post-Turonian, and pre-Tehama (late Pliocene). See also Peterson (p. 833).

Structural Geology

The Cretaceous rocks in the Ono quadrangle form an east- and southeast-dipping homocline, broken in the west-central part by faulting and folding.

Two sets of faults are prominent, one trending north-south and the other about N. 70° E. A third set of faults, trending northwest, is well developed in the Chanchelulla Peak quadrangle to the west, but only a few minor offsets of the basement contact have been found in the northwestern part of the Ono quadrangle (fig. 3).

NORTH-TRENDING FAULTS

Displacement has been greatest along the north-trending faults. Fractures in the north part of the quadrangle are transverse faults and those in the south, strike faults. Movement on the transverse faults may be predominantly strike-slip, whereas that on the strike faults may be predominantly dip-slip.

North-Trending Transverse Faults

The Huling Creek fault offsets the basement contact with a right lateral displacement of more than 2,000 feet. The fault trace is almost totally masked by alluvium and dense brush but can be seen in the bed of Huling Creek just below the high conglomerate ridge overlooking the Ono-Igo road.

This fault is interpreted as having a large strike-slip component and in part trace-slip displacement because of a change of lithologic facies across the fault and because fossil zones higher in the section are not displaced. The Huling Member, and the conglomerate below it, are thick units (850 feet and 500 feet, respectively) on the east side of the fault, but west of the fault the Huling Member is thin and the conglomerate unit is absent. This suggests that the principal component of movement of the west block was toward land or source area, bringing thinner sandstone and mudstone originally deposited farther offshore against thicker conglomerate and sandstone originally deposited several thousand feet nearer the source area. The fossil zone immediately above the Huling Member has been traced without apparent offset across an area of complex structure believed to be a continuation of the fault. These two facts suggest trace-slip movement along part of the fault. If trace-slip movement has occurred, the basement contact, which is offset about 2,000 feet horizontally, must dip more steeply than the overlying sedimentary rocks. This cannot be confirmed because of the irregularity and gradational nature of the contact, but it is inferred to be true.

The Huling Creek fault apparently dies out in the wide bands of slickensided mudstone and minor folds where its extension would cross the North Fork of Cottonwood Creek. Beds of the Bald Hills Member have been traced across its projection without deformation.

The Watson Gulch fault is near the west edge of the quadrangle, and, like the Huling Creek fault, is a right-lateral fault that offsets the contact between the basement rocks and the Cretaceous sediments for nearly one mile. It also resembles the Huling Creek fault in that the Cretaceous units on each side of the fault (e.g. Roaring River Member) are considerably disturbed, but not greatly offset. Again this is best explained by postulating a large strike-slip component to the movement of the fault. For the conglomerate beds of the Roaring River Member, this would be nearly trace-slip movement.

North-Trending Strike Faults

Most of the strike faults are in the southwest quarter of the quadrangle. Exposures and topographic expression indicate that most of these faults are nearly vertical. Those plotted on the map place thickly bedded sandstone units against, and updip from, mudstone units. Since the sandstone units are not repeated and do not appear at the surface on the opposite side of the fault, a dip-slip movement is inferred. The movement was up on the west side of most of the mapped faults.

NORTHEAST-TRENDING FAULTS

A number of small displacement faults in the southern half of the quadrangle trend N. 60° to 75° E. Faults of large displacement with the same trend are present near Beegum in the Chanchelulla Peak quadrangle, and Irwin (1960b, pl. 1) mapped a major fault zone with this trend near the Cold Fork of Cottonwood Creek in the Colyear Springs quadrangle to the south. This trend is also characteristic of virtually every sandstone dike in the area, and these faults and dikes probably are related genetically. The dikes were emplaced sometime between late Turonian and late Pliocene, and the whole northeast-trending fault system probably dates from this interval.

NORTHWEST-TRENDING FAULTS

Several northwest-trending faults offset the basement contact, but only one has a large displacement. This fault, poorly exposed in the Ono quadrangle, is inferred to offset the Roaring River Member west of Tar Bully in the western part of the area and probably is an extension of a fault clearly exposed in the bed of Duncan Creek, one-quarter mile upstream from the Graves Ranch house in the adjacent Chanchelulla Peak quadrangle. The Graves Ranch fault is difficult to interpret because the basement contact is offset in a direction opposed to the offset of the Roaring River Member. This is best explained by postulating a large strike-slip component, and a direction of movement which bisects the angle between the plane of the basement contact and the plane of the beds of the Roaring River Member.

Mappable displacements along well defined zones are limited almost entirely to faults that cut the basement contact. The distance these faults are traced through the Cretaceous rocks seems to be a function of the amount of offset of the basement contact. This conclusion points up the difficulty of recognizing displacements in the Cretaceous rocks. However, the observations suggest that the fractures are the result of stresses in the basement rocks and that the propagation of the

fracture into the overlying rocks depends on the magnitude of the basement displacement and the nature of the superficial rocks. From the above observations, we explain the wide zones of mudstone and siltstone, in which every broken surface displays slickensides, as the termination of faults by distribution of the movement through broad zones. Also we infer that the faults were contemporaneous post-Turonian, pre-Pliocene fractures that never reached the surface—the buried epicenters of some Tertiary or Late Cretaceous earthquake.

The relative ages of the different sets of faults are not easily determined. North-trending faults in the northern part of the quadrangle probably are younger than, or contemporary with, the northwest-trending set, and the northeast-trending set probably is contemporary with, or younger than, the other two sets.

Evidence for the first conclusion is in the area where the Watson Gulch and Graves Ranch faults meet. This area is poorly exposed and contains no mappable beds. However, a zone of deformation marked by erratic attitudes and sheared rocks extends south of their junction, whereas the rocks to the southeast are relatively undisturbed. In addition, a smaller fault, trending parallel to the Graves Ranch fault two miles to the north, is truncated or dies out against the Watson Gulch fault.

Evidence for the second conclusion lies in areas mostly outside the Ono quadrangle (fig. 3), but it is also suggested by the faults along Budden Canyon, Big Salt Creek, and the Middle Fork of Cottonwood Creek, all of which appear to offset the north-trending set of faults. The northeast-trending faults truncate the northwest-trending set in several places near Beegum in the Chanchelulla Peak quadrangle.

A point in favor of the contemporaneity of the various sets of faults is the interjection of sandstone dikes along fractures parallel to the northeast-trending faults. The size and extent of the dikes indicates considerable pressure in the parent chamber. It seems that a previous strong deformation would have either caused earlier injection or would have reduced the ability of the sands to flow by providing fractures along which the contained water could escape.

FOLDS

Two anticlines and a syncline are present in the Fiddler Creek-Wilson Creek area near the west edge of the map. These structures are related, at least in part, to the deformation that caused the faulting. The north-trending anticline which involves conglomerates of the Roaring River Member is broken on the west limb by the Watson Gulch fault. The syncline in the Roaring River conglomerates immediately west of this fault has both limbs truncated against faults. The anticline along Fiddler Creek apparently is related to the faults also. The folds and faults die out up-section. Beds of Aptian age are the youngest rocks involved in the folding in the Fiddler Creek area. The Huling Creek fault apparently dies out partly in a fold, involving beds of Albian age, which is exposed on the North Fork of Cottonwood Creek.

Small folds are especially numerous in the Fiddler Creek area where they plunge more or less parallel to the major fold axis. Small non-tectonic slump folds are also common and may be mistaken for tectonic disturbances where exposures are poor.

UNCONFORMITIES

The unconformity separating the Cretaceous rocks from the earlier formations is a regional unconformity that probably extended over most of northwestern California. The general direction of transgression of Cretaceous seas in the Ono and Chanchelulla Peak quadrangles is north and east. Cretaceous rocks lying on this surface are progressively younger toward the north and east. The Cretaceous section also thins in this direction and is only one-third as thick on Huling Creek as along Dry Creek-Budden Canyon (Ono and Chanchelulla Peak quadrangles). Most of this thinning is due to overlap. Near Beegum, in the Chanchelulla Peak quadrangle, the sediments on the basement are early Hauterivian in age. At Ono they are late Hauterivian, and in the Clear Creek area (Anderson and Redding quadrangles) the age is middle Albian. East of Redding, Turonian sediments lie on the unconformity.

The writers believe there are no regional unconformities within the Cretaceous section in this area. However, evidence exists for unconformities of considerable importance in adjacent areas, probably to the east. In the northern part of the Ono quadrangle the lower conglomerate beds of the Bald Hills Member contain reworked fossils from earlier Cretaceous rocks (Murphy and Rodda, p. 838). These fossils include Barremian, Aptian and Albian species and are characteristic of beds as much as 2500 feet lower in the section as exposed in the Ono quadrangle. They could have been derived only from the erosion of a considerable thickness of strata.

At some outcrops in the northern part of the Ono quadrangle, slightly angular relations between the Huling Member and the underlying beds have been observed. This fact and the marked faunal and distinct lithologic change across this contact have suggested the presence of an unconformity. The missing faunas are those of the early Aptian stage; but, as mentioned earlier, we do not yet have a firm hold on the age of the upper part of the *Shasticrioceras poniente* fauna. A more pronounced discontinuity may be present at this stratigraphic level nearer the old shoreline, which we believe to have been east and possibly north of the present outcrops.

The conglomerates of the Roaring River Member may indicate a rejuvenation of the source area and areas nearer the source area with concomitant partial destruction of older Cretaceous deposits, as indicated by the local lenses of limestone fragments similar to the concretionary limestone lower in the section. However, no evidence was discovered to indicate that the continuity of the sedimentation was interrupted in this area.

OTHER DISCORDANT RELATIONSHIPS

Numerous observations of angular relationships of two sets of strata were made during the course of

this work. The discordance resembles an angular unconformity at some localities (e.g., Little Salt Creek, Sec. 23, T. 29 N., R. 8 W.; Wells Creek, Sec. 27, T. 28 N., R. 8 W.; North Fork of Cottonwood Creek and Eagle Creek, Sec. 11, T. 30 N., R. 7 W.; a tributary of the North Fork of Cottonwood Creek, Sec. 29, T. 30 N., R. 6 W.). In other places, the overlying beds are truncated by those below, but bend into the contact like drag features along a fault (e.g., Big Salt Creek, Sec. 30, T. 29 N., R. 8 W.; a tributary of the North Fork of Cottonwood Creek, Sec. 20, T. 30 N., R. 6 W.).

We prefer the interpretation that these features result from soft-sediment deformation, sliding and slumping, rather than from tectonic deformation because (1) they are virtually limited to single exposures; (2) they are associated intimately with other features reflecting instability; and (3) neither rock units nor fossil zones are repeated. Many indications of instability of the sediments in the depositional environment are present (e.g., cobble and boulder mudstones, pull-apart bedding, and intrastratal deformation), and the angular relationships described above are more easily explained as additional manifestations of instability rather than unconformities or thrust faults.

CENOZOIC ROCKS

The post-Cretaceous rocks in the Ono quadrangle are the Tehama Formation (including the Nomlaki Tuff), the Red Bluff Formation, and later alluvial deposits, mostly gravel on river terraces.

Cenozoic non-marine rocks on the west side of the Sacramento Valley were divided originally by Diller (1894, p. 411–419) into three units: The Ione Formation at the base, the Tuscan Tuff in the middle, and the Red Bluff Formation above. The names Ione and Tuscan had been applied previously to different rocks elsewhere in the Sacramento Valley and are not present in the Ono quadrangle. The Red Bluff Formation of Diller was named for exposures near the town of Red Bluff in Tehama County, and included silt, sand, and gravel; the entire section lies above the prominent tuff.

Russell and VanderHoof (p. 12–14) redefined these rocks, and included most of them in a new unit, the Tehama Formation. They considered the prominent tuff to be a member of the Tehama Formation and named it the Nomlaki Tuff from exposures on the old Nomlaki Indian Reservation in western Tehama County. The Red Bluff Formation was restricted to soft, thin, red beds of coarse sand and gravel lying on the Tehama Formation and separable from it by the color and generally coarser grain size. No type locality, other than Tehama County, was given for the Tehama Formation.

C. A. Anderson and Russell (p. 235, pl. 3) outlined the distribution of these units on a small scale map of the Sacramento Valley, and gave criteria for the distinction of the two units as follows: "Although both the Tehama and Red Bluff vary considerably in grain-size at any locality where both are exposed, the Red Bluff is usually much coarser; this feature, together with the red color of the Red Bluff, serves to distinguish it easily from the underlying Tehama." These criteria, though generally adequate, can be shown to give erroneous results when applied in the Clear Creek area and in the northeast part of the Ono quadrangle. Anderson and Russell (p. 238, fig. 11) themselves gave the name Red Bluff to gravels on stream terraces which lie at least 100 feet below the general upper surface of the Tehama sediments in this area. Other writers (Olmsted and Davis, p. 81) have experienced difficulty in separating the two units and, in parts of the Sacramento Valley, include the Red Bluff and Tehama in a single cartographic unit.

Although the two units are real and distinct, they can be separated with assurance only where exposures are good. Since they are poorly exposed in the Ono quadrangle, we have shown the Red Bluff and Tehama Formations as a single cartographic unit.

Tehama Formation

The Tehama Formation in the Ono quadrangle is composed of yellowish-brown sediments ranging in size from silt to fine gravel. The beds are lenticular; sedimentary structures generally are obscure, although cross-stratification is present in many coarse sand and pebble beds. The thickness of the Tehama Formation is variable; the maximum in the Ono quadrangle is about 300 feet.

The Tehama Formation is unconformably overlapped by the Red Bluff Formation with a small angle between the bedding planes. This overlap trends along a north-south line connecting points about a mile and a half west of Rosewood and a mile west of Gas Point.

The Nomlaki Tuff Member is identified by Anderson and Russell (p. 246) as a dacite tuff. A sample taken along Dry Creek is composed of a light brown matrix, probably altered glass (about 30%), altered pumice (20%), plagioclase (30%), and minor amounts of green hornblende, biotite (fresh and dull), magnetite in octahedra and balls, and andesite fragments. The Nomlaki Tuff crops out in bluffs along stream courses and commonly is pinkish white or yellow at the surface. The maximum thickness of the Nomlaki Tuff in the Ono quadrangle is about 15 feet.

In Tehama County the Tehama Formation has been dated as latest Pliocene on the basis of fossil vertebrates from localities 10 and 200 feet above the Nomlaki Tuff (Russell and VanderHoof, p. 17–21; VanderHoof, p. 384).

Red Bluff Formation

The Red Bluff Formation is composed of gravel in a clayey-sand matrix. The clasts are derived mostly from metamorphic rocks of the type now exposed in the Klamath Mountains; pebble conglomerate characteristic of the Bragdon Formation, gneiss, and vein quartz are common. Clasts of volcanic or sedimentary rocks are rare.

The thickness is variable and in most places unknown. In the southeastern part of the quadrangle it is locally at least 250 feet thick.

Photo 10. Typical clasts from the Red Bluff Formation, Sec. 25, T. 29 N., R. 7 W. The clasts in the Red Bluff Formation are generally larger, less rounded, and different in composition than the clasts in the Cretaceous conglomerates. Their main source was a metamorphic terrain, whereas the Cretaceous conglomerates were derived from volcanic, sedimentary and igneous terrains.

The predominantly metamorphic composition, larger size, and generally subrounded to subangular clasts in the Red Bluff and later gravels contrast markedly with the well rounded, predominantly sedimentary, volcanic, and chert clasts of the Cretaceous conglomerates. Little if any material in the Red Bluff Formation is derived from Cretaceous rocks of the region. Red Bluff gravels are generally coarser than Tehama gravels and the Tehama Formation probably did not contribute greatly to the Red Bluff Formation (Anderson and Russell, p. 242).

Terraces and Terrace Deposits

As many as six terrace levels can be distinguished along the major streams draining the Ono quadrangle. Suggested correlation of the terraces is shown on the geologic map by numbers from 1 to 6 placed on each terrace. The last-formed terraces are labeled number 1; higher numbers indicate increasingly older terraces. Upstream terraces are cut on Cretaceous rocks; downstream terraces are cut on the Tehama and Red Bluff Formations. Most terraces have thin veneers of gravel similar to Red Bluff gravel. Along the lower reaches of the major tributaries of Cottonwood Creek, the narrow modern channel and floodplain deposits are indicated by the symbol Qal and not by a terrace number. The terraces and terrace deposits were produced during several post-Red Bluff stages of erosion. One terrace set indicates the streams were perched 50 to 100 feet above the present streams, and the valleys were wider and more subdued. These wider valleys are especially well developed on the Middle Fork of Cottonwood Creek.

Many of the terrace deposits have been worked for gold, and the tailings and workings of the operations mar the landscape along the lower courses of most of the larger tributaries of Cottonwood Creek.

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EXPLANATION

- Qal — UNDIFFERENTIATED: Alluvium and Bridge Tailings, including glacial and alluvial deposits on Cottonwood Creek
- 1, 2 — LOW TERRACES: Mostly 5-20 above present stream level
- 3, 4 — INTERMEDIATE TERRACES: Mostly 40-90 above present stream level
- 5, 6 — HIGH TERRACES: Over 100 above present stream level, 6 is interpreted as being the upper surface of the Red Bluff Fm.

ALLUVIAL TERRACES AND TERRACE DEPOSITS: Unconsolidated to semi-consolidated gravel, sand, silt and clay; gravel is mostly well-rounded, composed of rock types common to the present watersheds; terrace deposits are commonly reddish in color

QUATERNARY

TERTIARY & QUATERNARY

- TQrt — Tin — RED BLUFF AND TEHAMA FM: Predominantly coarse grained reddish, clayey gravel composed of rock types common in the Klamath Mts. Tin is tuffaceous member.

- Kbg — GAS POINT MEMBER: Moderate gray limestone, tan sandstone and interbedded sandstone and mudstone
- Kbb — BALO HILLS MEMBER: Lenticular sandstone and conglomerate, gray shale interbedded with mudstone, locally sharply porphyritic volcanic rocks and dark chert
- Kbc — CHICABALLA MEMBER: Mudstone with minor sandstone beds and calcareous concretions
- Kbh — NULING MEMBER: Fine to coarse grained, poorly sorted sandstone
- Kbrr — ROARING RIVER MEMBER: Lenticular sandstone and conglomerate units interbedded with mudstone, locally sharply porphyritic volcanic rocks and chert
- Kbo — OGO MEMBER: Predominantly thin bedded, fine grained sandstone and interbedded mudstone, some conglomerate and thick bedded coarse grained sandstone
- Kbr — RECTOR MEMBER: Cobble-boulder conglomerate derived from local basement complex

BUDDEN CANYON FM

CRETACEOUS

- sg — SHASTA BALLY BATHOLITH: Chiefly hornblende diorite, quartz diorite and granite with some gabbro
- s — SERPENTINE: Serpentinized ultramafic rock

JURASSIC OR CRETACEOUS

- Cmb — Slate and conglomerate
- Dc — COPLEY GREENSTONE: amphibolite, schist and hornfels

MISSISSIPPIAN(?) DEVONIAN(?)

BRAGDONATI FM

- sch — ABRAMS MICA SCHIST and TALMON HORNBLENDE SCHIST: Chiefly feldspathic and micaceous quartz schists, hornblende schists and gneisses, quartz and silicate bearing calc-schists

PRE-DEVONIAN(?)

SYMBOLS

- Contact — Dashed where approximately located (within 400 ft)
- Fault — Dashed where approximately located, dotted where concealed, queried where uncertain, U, upthrown side, D, downthrown side
- Fault, showing relative movement
- Fault zone
- Axis of anticline
- Axis of syncline
- Plunge of minor anticline
- Plunge of minor syncline
- Strike and dip of beds
- Strike and dip of foliation in metamorphic rocks
- Apparent dip of bedding and foliation in cross-sections
- Strike and dip of joints
- Sandstone dikes

LITHOLOGY

Sandstone | Conglomerate | Limestone

Mappable unit

Key unit

TOPOGRAPHIC BASE MAP BY U S GEOLOGICAL SURVEY

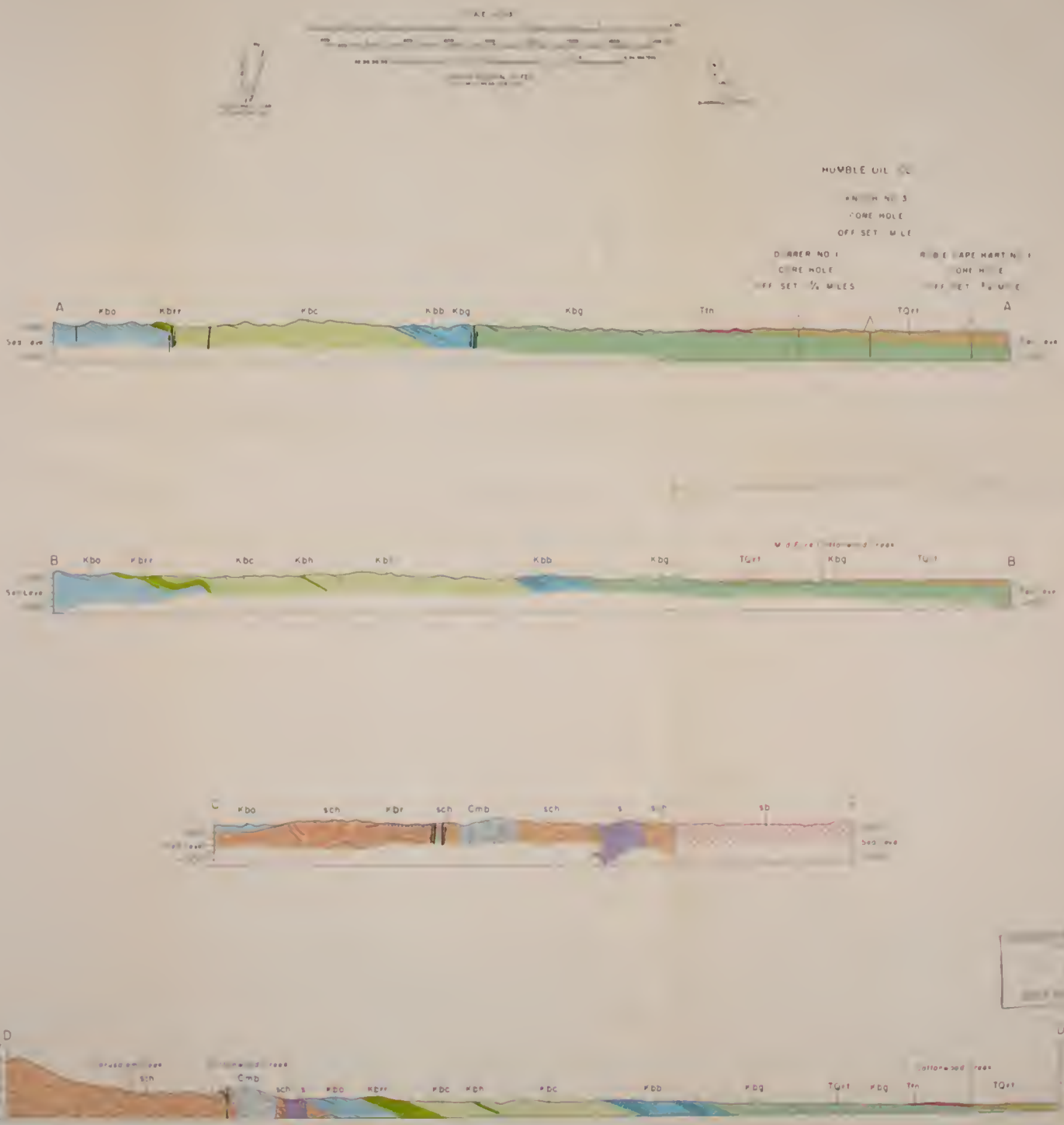
GEOLOGY MAPPED BY M A MURPHY, P U RODDA AND O M MORTON, 1951 TO 1963

GEOLOGIC MAP AND SECTIONS OF THE ONO QUADRANGLE, SHASTA AND TEHAMA COUNTIES, CALIFORNIA

BY

M. A. MURPHY, P. C. RODDA AND D. M. MORTON

1968



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